

The VSL Discussion: What Does Variable Speed of Light Mean and Should we be Allowed to Think About ?

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February 1, 2008

Abstract

In the past years, variable speed of light (VSL) theories have been of growing interest but also a subject of controversial discussion. They have been accused both for tautologies and for violating special relativity, and concerns have been expressed about the validity of such approaches in general (e.g. Ellis, astro-ph/0703751). Without trying completeness on the issue, the example of Einstein's VSL attempts (1911) and Dicke's 'electromagnetic' theory (1957) are urged to give some comments on the above criticism.

Introduction

Exotic theories. Of course, 'variability' can encompass a lot of aspects. One may introduce dispersion, considering a dependency on λ , or on v , violating Lorentz-invariance. Most of these proposals do not have sufficient experimental support at the moment, though many of them are interesting and seem as good as inflation for resolving the flatness and horizon problems in cosmology; this however is not the focus of interest here, since comments on [1] with respect to modern VSL theories [2] have already been given [3]. There, appropriate reference and a clear discussion of older attempts are however missing. These so-called [2]

Conservative theories suffered an even harsher 'Not even wrong'- criticism of being tautological. The argument is the following: 'One assumes a good clock can be constructed, and then uses the timing of reflected electromagnetic radiation to determine the distance. But then the (physical) speed of light of necessity has to be unity, precisely because all electromagnetic radiation travels at the speed of light, and distances are being determined by use of such radiation.' ([1], sec. 2). One may wonder what fact

should be proven by that statement. All that follows indeed from the definition of SI units, but in my humble opinion something can either be measured or defined, not both. Thus $c = 1$ is not a physical necessity but at best a mathematical convention; one may further ask if it is a possible, reasonable or even the only practical one. At the very end, this is not a scientific question; to illuminate the practical value of $c = 1$, we investigate the following toy theory:

Meteorology at constant temperature

Fortunately, glass and most fluids have different thermal expansion coefficients (TEC), and for that reason we easily construct thermometers based on the expansion of fluids with respect to the containing tube. But imagine all substances had the same TEC, things wouldn't be that easy! All thermometers made in that fashion would show the same temperature. Well, one still could measure temperature by means of the mean quadratic velocities of particles in a gas. Determining the velocities with clocks and rods and deriving the temperature would still be possible. But what if the same velocity is used for the *definition* of time and length scales? A gas thermometer in a cold location would then just mimic a

slower running time and/or a contraction of length scales. One realizes that in such a world it is not easy to detect temperature differences, but *there is* an effect: the velocity of sound waves, depending on temperature, would be a function of place and time, and hence, differences in temperature would cause a deflection and focussing of sound waves.

Mind now the following mathematical insight: there cannot be any doubt that the numerical value of temperature depends on arbitrary chosen units, and since it is a dimensionful quantity, it can be set to unity in every point (see argument [1], sec. 2). Therefore, mathematicians should feel free in formulating meteorology (or, appreciating generalizations, thermodynamics) with $T = 1$, but the demand that any weather forecast should be expressed in this manner will be of limited usefulness. People who do not shy elementary material should have a look at the textbook example in Feynman's lectures II, chap. 42 [4]¹.

Differential geometry. I shall like to draw attention to the fact that such a convention ($T=1, c=1$) leads to a curved space, which equivalently can be described by a metric. However it is quite a difference if one can choose an -arbitrary-unit *globally* or if you have to do this *locally* in every point. In the later case such a choice $T = 1$ can turn out to be complicated. The 'proof' instead that 'physically' c is always a constant is like the proof of a differential geometer that physically no mountains exist, since in every point of a differentiable manifold one can attach a flat tangent space (the necessity to change direction when walking uphill is nothing physical, just a 'connection'). What a nice revival of the earth as a plane! We proceed a little further in history and listen to those who first considered a variable speed of light:

Einstein and a VSL.

The first who realized that a variable speed of light may cause astronomical light bending was Einstein in 1911 [6]:

'From the proposition which has just been proved, that the velocity of light in the gravitational field is a function of

¹Though being a toy theory, there are very interesting comments regarding the topic given by Landau [5], par. 8.

the place, we may easily infer, by means of Huygens's principle, that light-rays propagated across a gravitational field undergo deflexion'.

As a consequence of a variable speed of light, he considered variable time scales only and postulated

$$\frac{dc}{c} = \frac{df}{f}, \quad (1)$$

which, as it is well-known, led to the (wrong) half value for the classical light deflection.² It was then Dicke³ with his 'electromagnetic' theory of gravitation [8] who discovered that the classical tests could be described by

$$\frac{dc}{c} = \frac{d\lambda}{\lambda} + \frac{df}{f}, \quad (2)$$

considering variable length scales, too. We shall not go into further details and refer the reader to the 'polarisable vacuum representation' of GR by [9], see also [10]. It is however at least an open question if GR can be formulated by a scalar VSL theory, instead of a 10-component metric! I shall not enter the fruitless question whether this is 'simple' or not - it's up to you whether you consider this an approach worth thinking about or share the above criticism: what a pity that Einstein in 1911 could not make use of check-lists like [1] - maybe he had stopped to develop weird theories about a curved spacetime...

Lorentz invariance. Such useful methodic guidelines would also have prevented Einstein from being in conflict with special relativity and remaining so blatantly unfamiliar with underlying principles of his own work - I wonder if this is the message the reader should learn from [1], sec. 4. In 1911, Einstein wrote:

The constancy of the velocity of light can be maintained only insofar as one restricts ... to ... regions with constant gravitational potential...

²It should be noted that though c being a scalar field here, this theory is not a 'scalar' theory *coupled to matter* to which Einstein later expressed caveats. See also [7] for clarifying that point.

³It is not quite clear why Dicke gave up this interesting approach and followed up the quite different Brans-Dicke theory.

Indeed, such a VSL theory would require considerable reformulation on a technical level, but there is little doubt that this can be done as a matter of principle, as long as the local c is the limiting velocity. In continuum mechanics it is well-known that special relativistic effects show up [11], and a variation of the (corresponding) speed of transversal sound arises naturally. Further clarifying explanations are given by Dicke [8] and Ranada [12].

The Conditions a good physical theory has to satisfy

The necessity of compatibility with special relativity or Lorentz-invariance of a theory stressed by [1] is one of the most basic requirements new proposals have to satisfy in order to be taken seriously. Other requirements would be the possibility of a Lagrangian formulation, satisfying the equivalence principle, the agreement with general relativity, with quantum electrodynamics, to be renormalizable etc. All these are nice properties of successful physical theories. Setting up guidelines for the development of possible new ideas however does not provide any real progress. At the very end, there is only one really significant test: theories have to be in agreement with experiment and the observations. This basic need sometimes is forgotten, maybe because nowadays scientific methodology is quite dominated by mathematical constructions like string theory which have difficulties to get the link to experiments [13, 14].

Parameters, fields, and simplicity Not really a requirement, but a hint to a good physical theory is simplicity and economy of concepts; this is sometimes called ‘Occams razor’. Economy is hardly any more a property of physics’ standard models; particle physics has about 20 freely adjustable parameters, and cosmology, constrained to digest new data, is currently producing new ones[15]. In physics we have a dilaton field, an inflaton field, a Higgs field, dark matter, the cosmological constant became a quintessence field, not to mention numerous proposals with a shorter life time. Given that all that is undoubtedly convincing, is then anything else but $c \equiv 1$ too complicated physics ?

The need and the fear to change equations.

Paradoxically, postulating exotic new fields does usually little harm to the standard models, while the speed of light has a dominant role in various fields of theoretical physics [16]. VSL has obviously to consider the influence on other fields since changing c in one context only would be a rather weird and fruitless trial. On the other hand, despite all technical difficulties that may arise, the ultimate test remains the agreement with experiment, and due to the usual minute deviations a VSL causes we cannot expect that the corresponding observations become visible in all facets simultaneously. Of course, as [1] states, if one changes one equation, one has to change many ones, but this elucidates also the psychological problem that may arise: for somebody who has written a book full of formulas containing c , any VSL proposal becomes a nightmare.

Physicists in the ptolemaic period may have felt similarly when hearing about the earth being in motion. For somebody living in the 17th century, surely it wasn’t easy to get familiar with such a counterintuitive fact. But asking ‘if c is variable why don’t we measure a change ?’ is like asking ‘If earth is moving around the sun, why isn’t there a strong wind blowing due to that motion ?’. Galilei responded:

‘Close yourself with a friend in a possibly large room below deck in a big ship. [...] ...of all appearances you will not be able to deduce a minute deviation...’ [17]

It is a fact that the dynamics of a system we are part of are sometimes quite difficult to detect; for conservative people it is then much more evident to stick to the stationary image that maintains stability, and it is easy to ask questions like ‘How do you express formula xyz of the common formalism in the new formalism ?’⁴ Try to formulate the deferents and epicycles of the Ptolemaic world view in Newton’s language - what a medieval torture! Beholding the present situation of physics from a historical perspective (e.g. with the excellent popular book [17]) may be helpful to get a distance to the belief in the validity and generality of our present theories we use for starry-eyed extrapolations.

⁴[1], implication 2.

Outlook

To believe or not to believe if VSL is a promising approach in physics is not a scientific question; if one does not, he is free to continue the work he finds interesting to do. Thus it is not necessary to develop toolkits enabling a critique of any VSL paper [1]. We certainly do not need proofs that VSL cannot be an adequate approach, because (1) such a proof does not exist and (2) science has never advanced with such proofs. Neither we do need warnings that anything else than the standard model is dangerous, and statements like ‘if you think about anything else than the standard model, you have to deliver a complete solution immediately’ ([1], implication 5).

Physics needs the close link to experiments and observations and a freedom of ideas and methods.

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